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Climate Matters

News from the USGS Climate Research & Development Program

Volume 6, Winter 2017

About this issue

Changes in the environment, land use, and climate can have significant impacts on our Nation's economy, natural resources, infrastructure, and water, food, and energy security. Strengthening our country's resilience to these stressors requires a solid foundation of scientific information to improve model-based projections of change under different management scenarios.

Science Partnerships

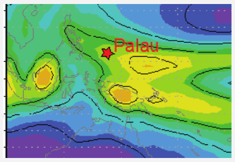
Improving avalanche hazard forecasting in a variable climate in mountain ecosystems

Science Highlights

Investigating drivers of tree mortality in western forests

Boreal vegetation and cycling of carbon and nitrogen

Changing fire regimes in the southwestern U.S. – implications for forest management and endangered species



Precipitation changes in the western tropical Pacific over the past millennium

Meetings

The 2017 Pacific Climate Workshop (PACLIM) will be held from March 5 – 8, 2017 in Pacific Grove, California. PACLIM brings together specialists from diverse fields, including physical, social, and biological sciences, to improve understanding of changing climate and land use on the eastern Pacific Ocean and western North America.

The 2017 American Association of Geographers (AAG) Annual Meeting will be held in Boston, Massachusetts from April 5 – 9, 2017. The AAG Annual Meeting is an interdisciplinary forum where leaders and experts from geography and its allied disciplines intersect to build new partnerships and collaborations.

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About this issue

This issue of *Climate Matters* focuses on the forest ecosystems in the western United States. These forests stretch from the boreal forests of Alaska through the giant sequoia forests of the Sierra Nevadas to the mixed conifer forests of the southern Rocky Mountains. All of these habitats are affected by a combination of climate variability and changes in land management, and research highlighted in this issue aims to improve understanding of factors that drive ecosystem change:

- How have natural changes in atmospheric circulation influenced precipitation over decadal and longer time scales?
- How frequent and severe were wildfires before and after institution of fire management protocols?
- Is tree mortality driven primarily by competition or by insects and pathogens?
- Do changes in boreal vegetation affect the amount of carbon and nitrogen released to the atmosphere?

Data generated in such studies provides real-world evidence needed to test and develop models to project changes under different land use and climate scenarios.

This issue also highlights a partnership between the USGS, Glacier National Park, and the National Weather Service that has resulted in development of an avalanche hazard forecasting program. This program provides real-time snow safety data needed to plan road clearing, forecast avalanches and storms, and aid fire and rescue personnel during the year. The capability to design multidisciplinary research projects to improve model capabilities and management strategies on a national scale is a unique role of the U.S. Geological Survey.

Climate Matters includes a sampling of the multidisciplinary research conducted by the Climate Research & Development Program to provide data and improve understanding on the rates, patterns, and consequences of changing environment, climate, and land use. It also highlights science partnerships with other Federal agencies. We welcome comments and feedback to shape future issues.

Debra Willard
Coordinator, Climate Research & Development Program

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Improving avalanche hazard forecasting in a variable climate in mountain ecosystems

Glacier National Park includes 1,583 square miles of picturesque glacier-carved peaks and valleys in northwest Montana (Figure 1), and its glaciers, scenery, and hiking opportunities make it one of the top ten national parks visited each year. The Going-to-the-Sun Road, constructed in the early 20th century, links the eastern and western entrances of the park, and reaches its highest point (6,646 feet) at Logan Pass, where it crosses the Continental Divide.

Figure 1. The rocky Garden Wall, shown here with Mt. Gould in the center, comprises part of the Continental Divide in Glacier National Park. The glacially carved landscape attracts millions of visitors each year.

The Sun Road, as it sometimes is called, is one of the Park's most popular tourist attractions and is the only road that traverses the entire width of the Park (Figure 2). The alpine section of the road climbs through cliffs midway from valley bottom to the crest of the Continental Divide. Vehicles traversing the road are separated from potential drops of thousands of feet by low retaining walls and barricades. The road closes every fall due to severe weather and heavy snowfall, with up to 80 feet of snow accumulating on the eastern side of Logan Pass at "The Big Drift". In the spring, clearing the road of snow requires ten weeks of plowing effort using heavy machinery. It is hazardous duty on the two-lane road, and avalanches from the slopes above can both delay opening of the road and present significant safety hazards to road crews and the public (Figure 3). In 1953, two plow operators were buried and killed in an avalanche. Heavy equipment used for snow removal has been pushed off the road by avalanches on more than one occasion.

Accurate avalanche forecasting is imperative for the safety of the snow removal operations and later use of the road by tourists, and it also has large economic impacts. Nearly three million tourists and snow enthusiasts visit Glacier National Park each year to enjoy the park's natural attractions. A joint study between the U.S. Geological Survey and National Park Service in 2015 reported $199 million spent each year by tourists in communities near Glacier Park. Delays in opening the Sun Road due to avalanche safety concerns can cost local communities dearly. A study sponsored by the National Park Service found that extended road closure has a $2.2 million per day impact on the local economy during the late spring.

USGS scientists from the Northern Rocky Mountain Science Center have been studying snowpack stability and shifts in snow melt, runoff, and mountain stream timing in collaboration with the National Park Service for the last 26 years. They expanded this work to provide information on the causes and frequency of snow avalanches, with a particular focus on wet snow avalanches which occur in the spring when snow melt weakens the strength of the snowpack. This is especially germane for the future since wet snow avalanches are likely to become more common with ongoing climate change.

Beginning in 2002, USGS began collecting data along the Going-to-the-Sun Road during spring snow removal operations to analyze and model the physical triggers for avalanche release, including snow structure and weather factors. This is a unique situation for studying natural releases of avalanches because explosives are not used to mitigate avalanche hazard as they generally are at ski resorts or other highway corridor operations. The research has two purposes: to provide real time data and avalanche hazard forecasting needed by park managers to evaluate safety and logistical impacts of avalanches, and to generate data needed to better understand the role of avalanches in mountain ecosystems.

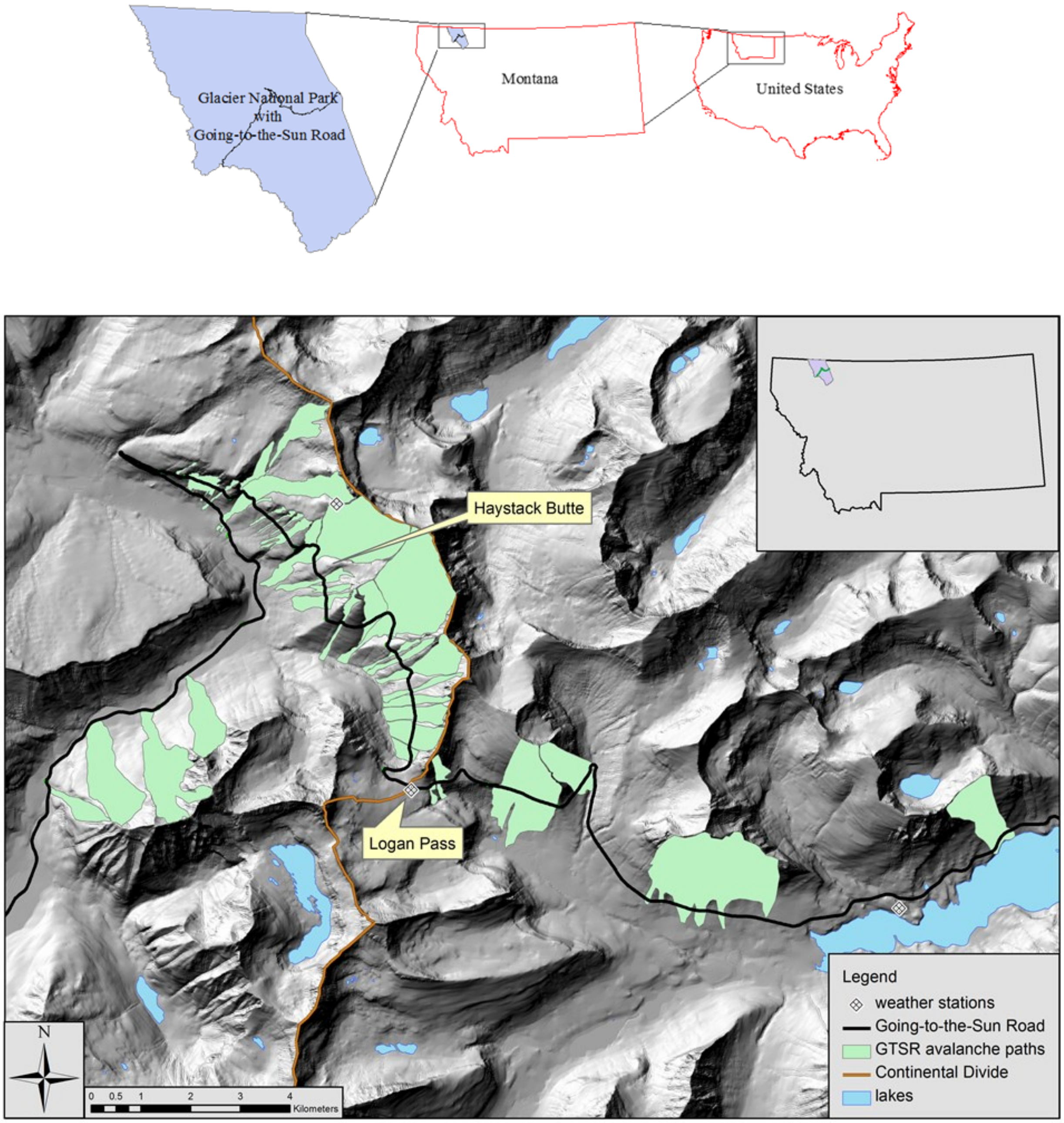

Figure 2. Location of Going-to-the-Sun Road in Glacier National Park, Montana. Shaded areas show avalanche paths based on historical observational data.

Figure 3. Glacier National Park Road Crew members clear a winter's worth of snow and avalanche debris from the Rim Rock area of the Going-to-the-Sun Road. Plowing operations typically begin April 1 each year.

The unique 15-year dataset is comprised of near-daily observations of avalanche occurrence and their size, type, location and destructive magnitude. Snow structure was examined in hundreds of snowpits for snow grain size and temperature gradients, both relevant characteristics for snowpack strength (Figure 4). The dataset also relies on a network of alpine climate stations established by the USGS to study snowpack accumulation history, density, stability, and timing of snow melt. These stations have been strategically placed adjacent to avalanche starting zones to better understand factors such as wind loading (Figure 5). They augment Snow Telemetry (SNOTEL) stations and National Weather Service stations in the region. Additional instruments have been added to the USGS stations for avalanche research that detect the onset of snowmelt and are directly incorporated into an avalanche-hazard forecasting program.

Figure 4. USGS staff record measurements of snowpack depth, structure, and water content near the Garden Wall weather station (elev. 7400 ft.).

Prior to the installation of this network of USGS weather stations, forecasts of avalanche hazards and extreme weather conditions were based on general observations of increasing wet snow conditions. According to Marty Whitmore, Warning Coordination Meteorologist from the National Weather Service (NWS), data provided by the USGS and other agencies greatly improved the accuracy of their weather forecasting. Real-time and near real-time data allow the NWS to verify and ground-truth forecasting of wind, temperature, and precipitation. The data provide point and spot forecasting support for local operations, especially during the 10-12 week period when the data from these stations are critical during snow plowing in preparation of the opening of Going-to-the-Sun Road. Accurate weather forecasting by the NWS improves public and property safety, avalanche safety, and the safety of the crew clearing the road.

USGS avalanche researchers and their collaborators have improved forecasting by developing a detailed

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Figure 5. The Garden Wall weather station (7400 ft.) provides real-time meteorological data for both avalanche forecasting and research. Sensors measure air temperature, relative humidity, wind speed and direction, incoming and outgoing shortwave and longwave radiation, and water flow through the snowpack.

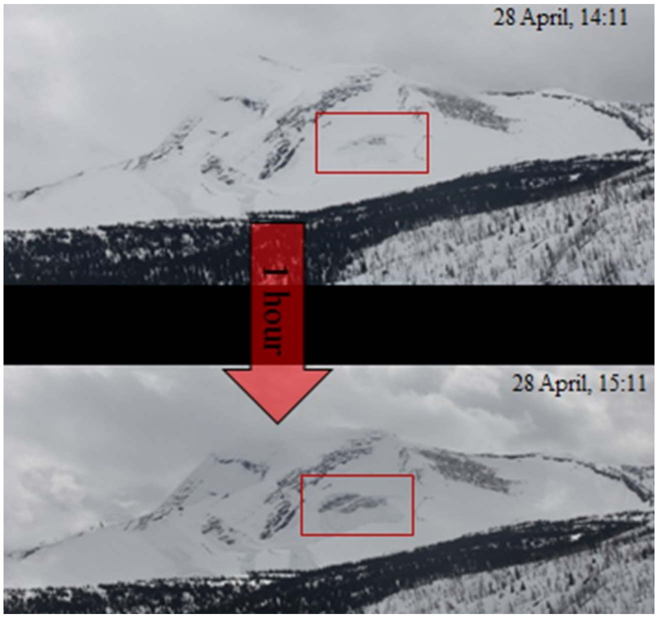

Figure 6. A time-lapse camera placed along the Going-to-the-Sun Road captures images every 15 minutes of Heavens Peak. This area harbors terrain capable of producing glide snow avalanches annually. The images can be used to detect snowpack displacement/movement by examining the change in dark versus light pixels in each image over time. The images also provide an accurate time stamp that allows for more precise association of meteorological parameters. The red box marks an area where an avalanche occurred during the one-hour time window.

GIS-based avalanche atlas that describes the physical and geographic characteristics of all the avalanches that threaten the Going-to-the-Sun Road. They used statistical models (such as classification tree analyses) to identify the meteorological conditions immediately leading up to large, natural wet snow avalanche releases. They studied tree-ring chronologies of trees damaged in avalanche paths to understand how frequently large destructive avalanches occur in established avalanche paths.

In recent research, their focus has been on glide snow avalanches, a specific form of wet snow avalanche that develops when meltwater in the spring percolates to the bottom of the snowpack and glides on the wet rock or vegetation underneath. As the snowpack glides, it creates a tear, or crack, on the surface of the snow. These glide avalanches are a special threat to the Going-to-the-Sun Road in the spring. A variety of methods used to study the onset and timing of glide cracks includes laser rangefinders (to safely measure their dimensions from a distance) and remote time-lapse cameras that record the hour during which they appear and, later, when they fail (Figure 6). USGS scientists have also classified all the terrain parameters of areas where glide cracks typically occur along the Sun Road and then used this spatial model to map all the other areas in the park where glide avalanches are likely to develop (Figure 7). All of these advances in avalanche knowledge are immediately incorporated into ongoing hazard forecasting because of the close working relationship of the NPS and USGS in Glacier National Park.

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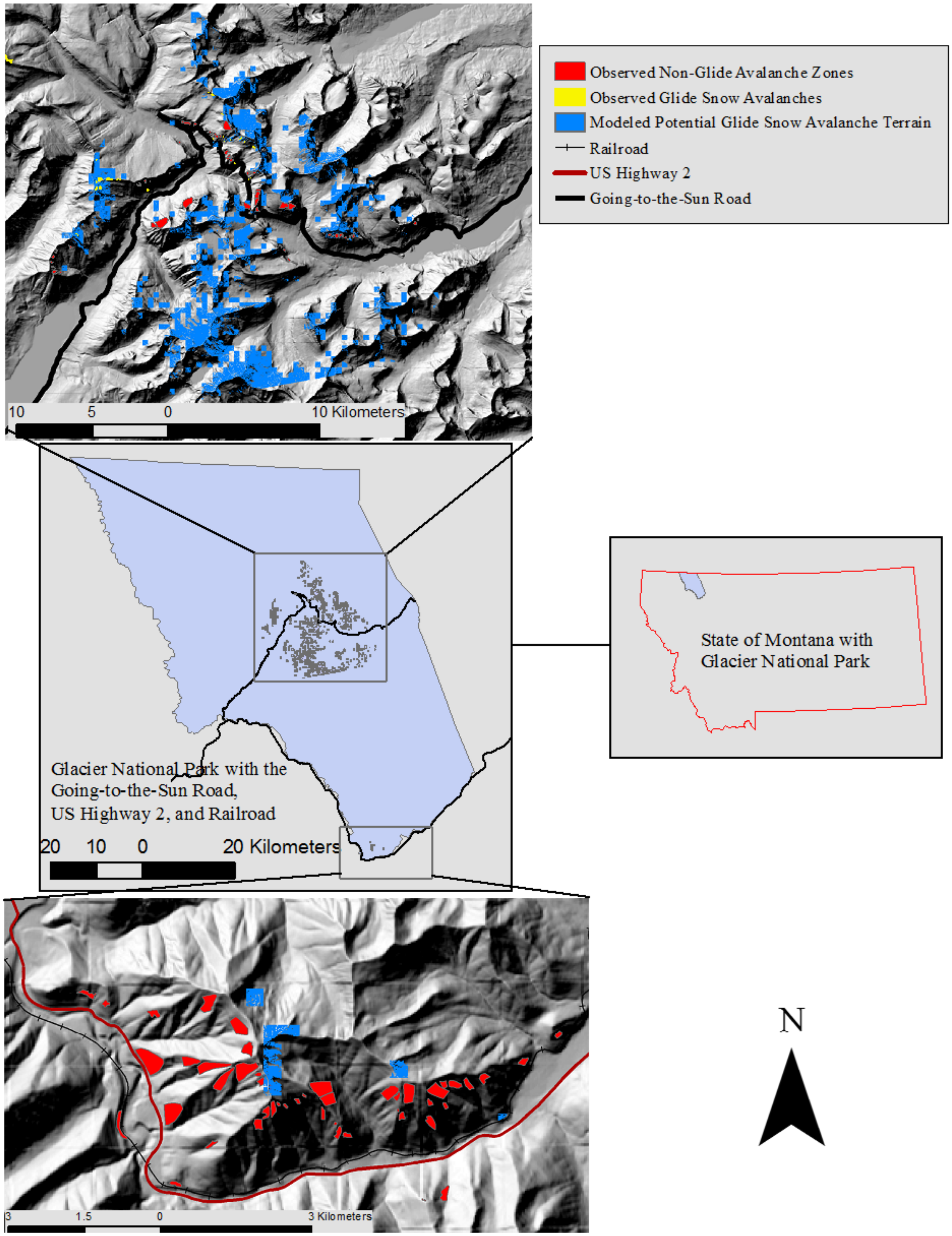

Figure 7. USGS researchers modeled terrain variables associated with glide snow avalanche release across Glacier National Park using a classification tree method.

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Most recently, USGS researchers are using relatively new remote sensing capabilities, such as LiDAR and Structure from Motion (SfM), in combination with traditional field sampling methods to assess avalanches as a safety hazard. The SfM utilizes multiple photographs to digitally create 3D surfaces (Figure 8). This provides a relatively inexpensive way to measure changes in snow depth and distribution over larger areas that will inform avalanche hazard evaluation. For glide avalanches, the USGS scientists have applied SfM to remotely measure the glide crack characteristics. Having such detailed data on timing, evolution, and size characteristics of major glide cracks, coupled with meteorological data, will advance our understanding of glide avalanche dynamics and the threats they pose.

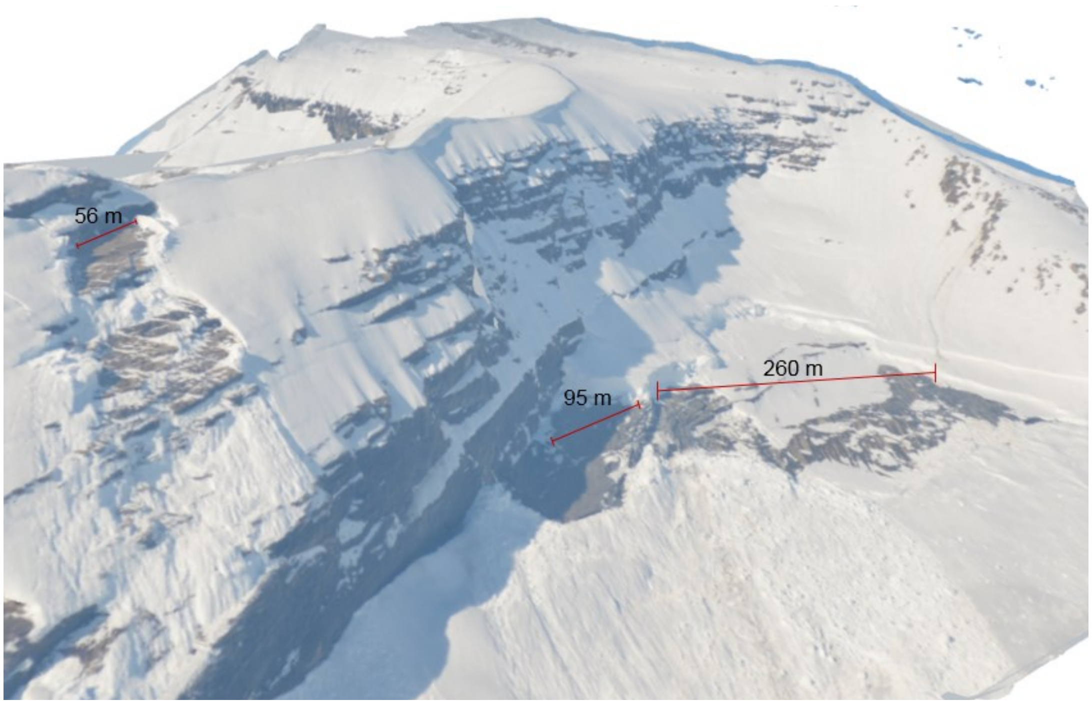

Figure 8. A 3D image of glide snow avalanche crowns created using Structure from Motion (SfM) photogrammetry. This method allows researchers to estimate avalanche crowns and detect change in snow depth and weak layer depth.

In addition to avalanche dynamics, researchers are also studying avalanche and climate associations using both long-term observational records as well as tree-ring analysis (dendrochronology). When avalanches impact a live tree they leave a scar that is evident in the tree rings. Scientists extract cores from live trees or cut cross-sections from dead trees to develop an avalanche chronology (Figure 9). This allows them to examine avalanche frequency and magnitude in the context of weather and climate patterns. This is valuable for understanding how specific weather patterns influence large magnitude avalanche occurrence, and avalanche frequency and magnitude in a changing climate.

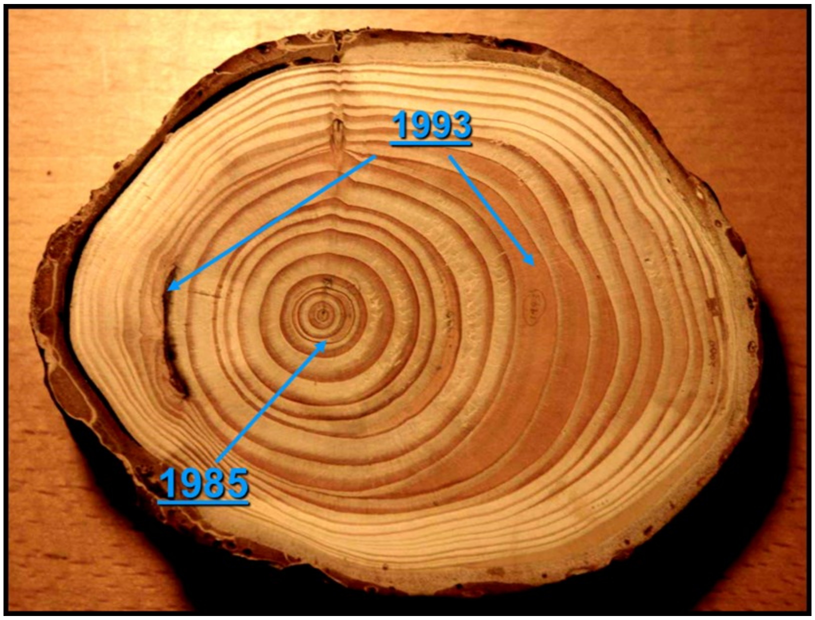

Figure 9. Avalanches injured trees in and along an avalanche path. USGS researchers examine avalanche and climate patterns by dating scars and reaction wood. This tree section shows scars and reaction wood from avalanches that occurred in 1985 and 1993.

The partnership between USGS and the National Park Service has helped ensure the transfer of new knowledge directly to the managers responsible for decision-making. Glacier National Park instituted its first formal avalanche hazard forecasting program in 2002, focused mainly on snow removal operations. In addition to forecasting, the program provides real-time snow safety and weather data to equipment operators and has increased avalanche awareness through regular avalanche safety training. The data also are used by the National

Weather Service, the USDA Forest Service, and others with crucial avalanche forecasting, rescue, fire, and predicting extreme weather and storms. This research provides value to these partners and the public as the variability of meteorological processes and frequency of extreme weather increases in a changing climate.

For more information, contact Dan Fagre or Erich Peitzsch.

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Investigating drivers of tree mortality in western forests

Forests play a critical role in the Earth's carbon cycle and climate system and provide us with other irreplaceable goods and services, such as clean water, hydrologic regulation, biodiversity, critical habitat, wood products, and recreational opportunities. Given their importance, understanding how forests might change in the future and what might drive those changes is becoming increasingly relevant.

In the western U.S., several large-scale tree mortality events have occurred during the last two decades. Some mortality has been driven by severe drought and bark beetle outbreaks. Additionally, background mortality rates -- the typical mortality in otherwise healthy systems – have nearly doubled in some forests in recent decades. Although less striking than the intense, localized diebacks, these small but widespread increases in background mortality rates can eventually lead to larger reductions in the amount of carbon stored in a forest.

An understanding of the causes of tree death is central to making projections of how forests might change in the future. It is a deceptively simple problem. We know some of the players: competition, bark beetles and other pathogens, among many others. However, we know surprisingly little about the relative importance of the factors that drive tree mortality or what environmental drivers cause them to come into play. Which tree-killing organisms should we focus the most attention on? Which are the ones that dominate mortality processes? Do they work in concert? Are there 'sleeper' organisms that might become more prominent as temperatures change or during a drought?

These questions have persisted largely because we have lacked adequate long-term datasets. Trees have long lives, and, barring major events, they simply don't die very often. Furthermore, information about what killed a tree gets obscured with time, so data collection soon after mortality death is critical. To address these questions, long-term research efforts are necessary, with scientists visiting trees on a regular basis.

Galleries made by the fir engraver bark beetle (*Scolytus ventralis*). The attack by this beetle ultimately girdled the tree and killed it.

The USGS has a long-term research effort in old-growth forests of the Sierra Nevada mountain range of California, and tens of thousands of trees have been tracked annually for decades. Researchers took advantage of this dataset to quantify the factors causing tree mortality. They found that biotic agents-- insects and pathogens-- appeared to dominate, with bark beetles in particular playing a key role. They also found that these organisms appear to act independently, rather than in unison, with the various agents largely acting opportunistically. Defoliators (insects that remove leaves from a tree or shrub) occurred infrequently, especially compared to bark beetles, suggesting that research that focuses on how a tree defends its stem, rather than the current focus on leaves, deserves more attention.

Understanding and quantifying the importance of biotic mortality agents are helping us improve models of forest change, which in turn will help managers strategically target their forest treatments. Most current models presume that tree mortality is driven primarily by competition, with other mortality being essentially random. Such models rarely make explicit attempts to characterize the impact of organisms such as bark beetles or the fungal pathogens that cause root rots. As the critical role of biotic agents is incorporated into models, managers will have more realistic tools to assess their landscapes and develop plans to adapt to an uncertain future.

In other words, when you think about the forest, you need to remember to see the insects for the trees.

The paper, "Why do trees die? Characterizing the drivers of background tree mortality", was published in *Ecology*. It is available at http://onlinelibrary.wiley.com/doi/10.1002/ecy.1497/full.

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Boreal vegetation and cycling of carbon and nitrogen

The boreal region, located just below the Arctic Circle, covers large parts of Alaska, Canada, and Russia. Boreal soils store more carbon (C) than the soils of any other ecosystem around the globe, making it very important to the global carbon budget. Model projections of climate change indicate a number of potential impacts on the boreal region, including increases in soil temperature, reduced amounts of snow cover, and thawing of permafrost (see Hinzman, 2005). These changes would alter the vegetation that dominates the landscape, which in turn would affect the amounts of carbon and nitrogen (N) stored in the soil. Less carbon stored in the soil means more carbon released to the atmosphere.

The boreal region is characterized by large forested areas, mostly comprised of coniferous trees such as spruce, pine, and larch. In Interior Alaska, these forests are dominated by black spruce trees (Figure 1). There also are ecosystems characterized by shrubs, grasses, sedges (grass-like plants that grow in wetter areas), as well as fens (a type of wetland that receives water from both groundwater and rainfall). Researchers from the US Geological Survey and University of Guelph measured the amount of carbon and nitrogen stored in soils of these five different ecosystems and age-dated materials within their soil profiles. With this information the scientists were able to determine carbon and nitrogen accumulation rates, over both decades and centuries (500-800 years). Their aim was to determine if, and how, these rates of varied by ecosystem type. With this information they could determine whether shifts in vegetation due to climate change would have an impact on the amount of carbon or nitrogen stored in soils.

Figure 1. The black spruce forest studied in this research. The soils of black spruce forests and other ecosystems within Interior Alaska store a great deal of carbon. This study examined how rates of carbon (and nitrogen) accumulation varied among different ecosystems. Boardwalks were installed to minimize the disturbance caused by researchers when visiting this site (Photo courtesy of Lee Pruett).

The researchers found that, over the past 60 years, no significant differences in carbon accumulation rates occurred among the five ecosystem types. This result demonstrates that, although the amount of carbon that enters and is lost from the soil may vary, the balance between these inputs and losses on the short-term is similar for all five ecosystems. Nitrogen accumulation rates for black spruce systems were lower than the sedge and fen ecosystems.

Over the century timespan, only the fen differed from the other four vegetation types. Carbon accumulation rates were 2-4 times higher in fens than the other ecosystems; nitrogen accumulation rates were 2-12 times higher. These results suggest that long-term carbon and nitrogen cycling in fens is fundamentally different from the other ecosystems. This difference likely results from differences in wildfire regimes, because fire not only releases large amounts of carbon and nitrogen to the atmosphere (combustion), but also affects post-fire nutrient cycling due to changes in soil temperature and moisture. Their shallower water table makes fens less likely to burn, even in dry years. If they do burn, the fires are less severe than in the other ecosystem types. Therefore, even though many fires have occurred in this region over the last several millennia, these fires had a smaller impact on the fens, resulting in more carbon and nitrogen being stored in the soil.

The results of this study suggest that regional soil carbon and nitrogen accumulation rates will not change significantly in response to shifts in vegetation between non-fen ecosystems. However, if climate change is extreme enough to reduce the amount of fens on the landscape, there could be a large decrease in the amount of carbon and nitrogen being stored with this region. This dataset will provide a useful baseline for comparison with future accumulation rates.

The paper, "Decadal and long-term boreal soil carbon and nitrogen sequestration rates across a variety of ecosystems", was published in Climatic Change. It is available at http://www.biogeosciences.net/13/4315/2016/.

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Changing fire regimes in the southwestern U.S. – implications for forest management and endangered species

Although fire historically played a significant role in structuring ecosystems throughout North America, recent "megafires" of the last decade have severely burned large tracts of land, with catastrophic impacts on housing, infrastructure, water supplies, forests, and wildlife. Forest managers have the paired goals of reducing fire hazards and restoring forests to provide a more natural fire regime and wildlife habitat. However, there is considerable debate on the historic role of high-severity fires in mixed-conifer forests, and restoration priorities and fire hazard reduction treatments have become increasingly contentious. USGS researchers are conducting research to determine historic patterns of fire frequency and severity in mixed-conifer forests of the southwestern U.S. to aid development of successful plans for forest management, restoration, and recovery of rare species.

Figure 1. Tree-ring sampling of a large Douglas fir with increment borers to determine tree age and records of past fires, such as growth suppressions or releases.

In the southwestern U.S., topographic variability results in a wide range of ecosystems and fire regimes. Low-severity fires that rarely kill canopy trees were historically common in the warm and dry ponderosa pine forests. In contrast, high-severity fires that kill large patches of canopy trees were common in the wetter and cooler spruce-fir and aspen forests. In between, the mixed-conifer forests likely had a mix of low- and high-severity fire. Research suggests that dry mixed-conifer forests that contain ponderosa pine were dominated by low-severity fire regimes. In contrast, wet mixed-conifer forests are thought to have burned with relatively large high-severity patches, but data are limited.

Beginning in the late 19th century, industrial-scale livestock grazing in the southwestern U.S. removed grasses and other herbaceous plants that historically carried surface fires. The grazing and subsequent active fire suppression allowed fuels to accumulate, which led to increases in both the severity of fires and the area burned. The 2011 Las Conchas megafire in the Jemez Mountains near Los Alamos, New Mexico burned more than 150,000 acres, including an incredible crown fire run that burned 44,000 acres in the first 13 hours. The large high-severity patches create by the Las Conchas fire had substantial impacts on wildlife, tourism, and flood potential, and has converted large areas to shrublands.

Threatened and endangered species are vital parts of many ecosystems but may pose additional challenges for forest management. The endemic Jemez Mountains salamander (*Plethodon neomexicanus*) was listed as a federally endangered species in 2013. The recent high-severity fires in its critical habitat (mixed-conifer forests) prompted its listing and increased the urgency to reduce fire hazard and restore forest structure. However, uncertainty about the natural role of high severity fire in mixed-conifer forests has led to public objections to restoration actions in these forest types. Scientists from the USGS and University of Arizona set out to document and compare current and historic forest structure and fire regimes in the Jemez Mountains salamander habitat (Figure 1). By improving understanding of mixed-conifer forest and fire ecology, the research aims to support forest management and salamander recovery efforts.

The researchers quantified the current mixed-conifer forest habitat (e.g., stand structure and composition) and compared it to tree-ring reconstructions of historical habitat, fire frequency, fire severity, and fire-climate relationships. The analyses of tree-ring records (Figure 2) show that historical fire regimes in Jemez Mountains salamander habitat were dominated by low-severity fire during the last four centuries, both in dry and wet conifer forests. Human land use - intensive grazing followed by fire suppression - has caused the current fire-free interval (> 116 years at all sites) to lengthen to more than twice the historical maximum intervals. After a

Figure 2. A partial cross-section from a live Engelmann spruce with three fire scars (1801, 1847, and 1880), indicating repeated, low-severity, moderate frequency surface fire in a wet mixed-conifer forest. Human land use - intensive grazing followed by active fire suppression - has excluded fire from this site for the last 131 years, which is almost three times the historical maximum interval (46 years).

century without fire, the forest understory has become denser and dominated by mesic, fire-sensitive tree species; in some cases, dry-conifer, fire-loving species, such as ponderosa pine have been pushed out. This research indicates that more than 40% of the sites converted from dry conifer to wet conifer forest in the absence of fire over the last century.

High-severity, tree-killing fire was a component of historical fire regimes in the wetter mixed-conifer forests; however it was patchy, and not as extensive as we have seen in recent megafires (for example, during the 2011 Las Conchas Fire, there were > 2,000 acre burn patches with no surviving trees). Historically, some sites switched from mixed- or high-severity fire to low-severity fire regimes during the last few centuries, likely in response to climate variability. The research showed that most severe fires occurred during the most severe droughts and the low-severity fires occurred during moderate drought.

This research highlights how both fire suppression and droughts have affected fire regimes, forest composition and forest structure in the western U.S. This suggests that the combination of increased fuel loads and projected increases in moisture stress due to warming temperatures could lead to increased fire severity. Such possibilities need to be considered as resource managers develop sustainable management strategies for endangered species that live in these forests.

The paper, "Historical dominance of low-severity fire in dry and wet mixed-conifer forest habitats of the endangered terrestrial Jemez Mountains salamander (*Plethodon neomexicanus*)", was published in *Forest Ecology and Management*. It is available at http://www.sciencedirect.com/science/article/pii/S0378112716302390.

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Precipitation changes in the western tropical Pacific over the past millennium

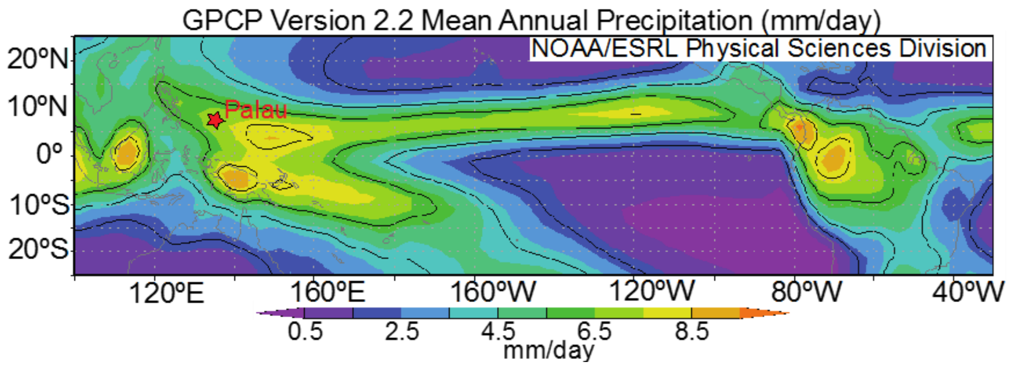

Figure 1. Climatic mean annual precipitation (mm·day-1) across the tropical Pacific Ocean (1979–2010 C.E.). Precipitation data are from the Global Precipitation Climatology Project (GPCP) Version 2.2 and provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA (http://www.esrl.noaa.gov/psd).

An intense band of thunderstorms circles the globe near the equator where the northeast and southeast trade winds come together, known as the Intertropical Convergence Zone (or ITCZ) (Figure 1). The most prominent rainfall feature on the planet, the ITCZ moves northward in the Northern Hemisphere summer, and southward during the Southern Hemisphere summer. As a result, many locations in the tropics to experience distinct rainy seasons and dry seasons. In addition to migrating north and south on a seasonal basis, it is hypothesized that the ITCZ shifts its mean position on longer timescales (e.g., decades to centuries) due to changes in the amount of solar radiation reaching the Earth's surface and other external forcing factors. Such shifts would cause a redistribution of rainfall across the tropics and have profound socioeconomic and ecological impacts in regions dependent on predictable rainfall patterns.

Researchers look to the paleoclimate record to see whether the ITCZ shifted significantly during warm and cool intervals in the past. Understanding the spatial extent and magnitude of rainfall changes during past climate events that occurred prior to our observations from rain gauges or satellites is important to improve the accuracy of predictions about the reorganization of rainfall patterns under different climate scenarios.

The Little Ice Age (LIA) was a cool period lasting from 1400 to 1850 AD when glacier advances occurred in the Northern Hemisphere and significant changes in rainfall and water availability occurred throughout the globe. Changes in the distribution of heat and precipitation in the tropical Pacific region can have far-reaching consequences, including impacts on droughts and weather patterns in North America. Understanding how the tropical Pacific responded to a climate event such as the LIA will help researchers better understand the drivers of some of the observed patterns in North America. Scientists from the USGS and University of Washington set out to investigate the shifts in the tropical Pacific rainfall patterns during the LIA using sediment records of the last 1,000 years collected from lakes in Palau. Palau is an island nation situated in the western tropical Pacific Ocean, at the northern extent of the modern ITCZ. The scientists used geochemical indicators to generate a proxy record of relative rainfall variability in Palau during the past millennium.

The rainfall reconstruction is based on the hydrogen isotopic composition of a molecule called dinosterol in lake sediments. Dinosterol is produced by phytoplankton (algae) living on the surface of brackish lakes, and its hydrogen isotopic composition effectively tracks mean annual moisture balance (evaporation minus precipitation). The study found that there was a shift toward drier conditions in Palau at the beginning of the LIA (around 1400 AD). Conditions in Palau became progressively drier until the mid-19th century, when a rapid return to wetter conditions coincided with rapid warming of the northern Hemisphere after the LIA. This Palau record, combined with other rainfall reconstructions from elsewhere in the tropical Pacific, suggests that Northern Hemisphere cooling during the Little Ice Age resulted in a southward shift of the ITCZ by as much 5º latitude.

Combined with studies from other sites in the tropics, this research is helping researchers map the magnitude of ITCZ fluctuations during different climate regimes in the past. This information aims to improve the ability of models to accurately predict the magnitude and spatial extent of fluctuations in ITCZ fluctuations in future climate scenarios.

The paper, "Precipitation changes in the western tropical Pacific over the past millennium", was published in *Geology*. It is available at http://geology.gsapubs.org/content/early/2016/07/12/G37822.1.abstract

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